TDA Assessment of Recommendations for Space Data System Standards

E. C. Posner and R. Stevens
Office of Telecommunications and Data Acquisition

NASA is participating in the development of international standards for space data systems. The purpose of this article is to provide a TDA assessment of the recommendations for standards thus far developed. The Recommendations for Telemetry Coding and Packet Telemetry provide worthwhile benefit to the DSN; their cost impact to the DSN will be small. They will be of advantage to the NASA space exploration program. Their adoption should be supported by TDA, JPL, and OSTDS.

I. Introduction

NASA is participating in the development of international standards for space data systems. Work on some of the system elements is mature and is being readied for concurrence by the participating space agencies.

The purpose of this article is to provide a TDA assessment of the recommendations for standards thus far developed. Recommendations for Telemetry Coding and Packet Telemetry are considered in detail; others, which are less well developed, are considered briefly.

A. Summary of Findings

The Recommendations for Telemetry Coding and Packet Telemetry provide worthwhile benefit to the DSN; their cost impact to the DSN will be small. They will be of advantage to the NASA space exploration program. Their adoption should be supported by TDA, JPL, and OSTDS.

Six other Recommendations were also reviewed. They all are less mature than the Telemetry Recommendations. They deal with standardizable elements of the system, and it is expected that they will lead to adoptable standards after the appropriate additional work.

B. Background

The Consultative Committee for Space Data Systems (CCSDS) is in the process of developing a set of Recommendations for standardization of space data system functions by space agencies. The purpose of the development is to enable economical cross-support between space agencies. From NASA's standpoint, it is expected that the Standards as issued by NASA in accordance with the Recommendations will also facilitate support of NASA's own missions by the Deep Space Network (and by TDRSS).

The CCSDS has representatives of European, Japanese, and other national space agencies, including NASA. JPL has several active members on the CCSDS Panels. The process of developing CCSDS standards Recommendations involves a sequence of increasingly mature documents: Concept Papers, White Books, Red Books, Blue Books. The details of the process are described in the CCSDS Recommendations Documents (e.g., CCSDS Recommendations for Space Data Systems Standards, Packet Telemetry, (Red Book) Issue-1, September 1983, page ii: "Document Status").

The Telemetry Coding and Packet Telemetry Recommendations are the farthest along. They are being readied for formal concurrence in March, 1984. The Coding Recommendation is based on mature technology. It is essentially the technique planned for use by Voyager 2 at Uranus.

The Packet Recommendation will produce a "leading standard." That is, its past applications to space data systems are few and have only demonstrated the concept, but its future potential is considered good. For example, a relatively simple adaptive packet telemetry system was used for the low rate channels on Seasat A with good success (Ref. 1). The system was very effective in supporting the ground data handling and distribution functions. Also, the JPL ISPM spacecraft data system design was initiated, but not completed, with a packet telemetry structure closely related to that of the present Recommendations. The JPL Mars Geoscience/Climatology Observer Project has made a preliminary assessment of using packet telemetry and has concluded that it would be cost effective (private communication).

In addition to the two Telemetry Recommendations, there are a number of others being prepared by the CCSDS Panels. They are:

(1) Time Code Formats (Draft Red, Blue Books)

(2) Packet Telecommand (White Book)

(3) Radio Frequency and Modulation (Concept Paper)

(4) Standard Format Data Units (White Book)

(5) Electronic Communications (pre-Concept Paper)

(6) Radio Metric and Orbit Determination (pre-Concept Paper)

Recommendations (2), Packet Telecommand, and (3), Electronic Communications, are expected to have the greatest impact on DSN service. However, none of these six are further discussed here.

II. Detailed Assessment of Impact of the Recommendations on the DSN

A. Summary of Approach

A block diagram of the DSN Telemetry System for the 1988-90 period was developed (see Fig. 1). It is a direct evolution of the mid-80's MK IVA; it includes the currently planned SFOC/NOC concept. In this, the current split of functions between the Mission Control and Computation Center (MC^3) and the DSN Network Operations Control Center (NOCC) is changed somewhat to reduce minor duplication, creating a Flight-Project implemented and operated Space Flight Operations Center (SFOC) and a DSN Network Operations Center (NOC). Using the diagram, the elements of the system that were seen to be affected by the Telemetry Recommendations were identified by a study team from the TDA Office.

Figure 1 depicts the DSN Telemetry System of the 1988-90 SFOC/NOC era. It encompasses that portion of the end-to-end telemetry system for which the DSN has responsibility. The diagram identifies those changes to the DSN Telemetry System that will be required to support missions using the CCSDS Telemetry Coding and Packet Telemetry Recommendations. It shows telemetry frame sync and Reed-Solomon decoding being done at the Signal Processing Centers (vs. the NOC) in a new "DSN Standard Decoder." The station location is not required by the Telemetry Recommendations, and may turn out not to be desired. In any case, the location chosen is independent of the requirements to support the standards. The Telemetry System and interface functions requiring changes related to the adoption of the Recommendations are identified in the boxes of Fig. 1.

The marginal implementation and operating costs for the DSN to adopt the Telemetry Recommendations were estimated. Also, the operating characteristics of the DSN incorporating the Telemetry Recommendations were assessed.

Finally, the suitability of the Recommendations for the JPL end-to-end space data system (Ref. 2) was considered, from a TDA perspective, by study team members who have participated in the JPL effort to develop the CCSDS Recommendations.

B. Assessment of Telemetry Coding Recommendation

1. Description. The Recommendation is CCSDS Blue Book, Draft Issue-0, February 1984. The coding is for the link between the spacecraft and the ground signal processing center. Proper coding and decoding of the link improves its performance by a factor of 5 to 7 dB at a bit error rate (BER) of 10^{-5}. The very low BER is needed to transport spacecraft science data that have been compressed and to enable effective use of packet data streams (Ref. 3).

The Recommendation proposes both an inner and an outer code. The inner code is a rate 1/2 constraint length 7 convolutional code with Viterbi decoding (Ref. 4). The outer code is a Reed-Solomon (255,223) block code with symbols from the 256-element field interleaved to depth 5 (Ref. 5). The inner code can be concatenated with the outer code, or it can be used separately as in Ref. 4. The coding is compatible with, but does not require the use of, the proposed packet telemetry concept. Also, an uncoded link is allowed.

Two changes to the original Red-Book Recommendation proposed as a result of the TDA assessment have been accepted by the CCSDS Panel, and incorporated into the draft Blue Book, upon which the discussion of this article is based. They related to standardizing on soft decision Viterbi decoding so that deep space missions can be assured of cross-support, and putting the packet sync word in the Reed-Solomon code blocks so that coding and packets are independent to aid testing and to allow independent evolution. They also foreshadowed the possible need to go to constraint length 7 rate 1/3 convolutional codes for some missions (Ref. 6).

2. **Impact on DSN.** Minor software and hardware changes are required in the Viterbi decoder, the Telemetry Processing Assembly, and their monitor and control interfaces. Also, frame sync and Reed-Solomon decoding hardware and software are required in the DSN to support the Recommendation. However, those sync and decoding functions must be provided by the DSN to support the SFOC/NOC concept for committed mission support, independent of the adoption of the standards. As we will see in a subsequent section of this article, the advantages of the Coding Recommendation outweigh the disadvantages.

Table 1 gives a summary of estimated implementation and operations costs for adopting the Telemetry Coding Recommendation. The costs involved are small ($70K). Specifically, the delta cost of providing the standard decoding capability is limited to the cost of implementing the capability to reverse the order in which the data symbols are sampled in the maximum likelihood-convolutional decoder. This single change provides compatibility with the "blue book" standard for Viterbi decoding.

Additional operational costs attributable to implementation of the Coding Recommendation are negligible, as testing and training of operators for a new decoder should be no more expensive than for maintaining the old capability. (Likewise, operational support of packet telemetry should be no more difficult to provide than with the present mission-unique interfaces.) In fact, once a standard has been adopted, testing and training should become simpler, as support will be required for only one data interface for all projects.

The Coding Recommendation is fundamentally sound. Some details will probably need modification in application. The basic technology embodied in it has had extensive development and flight/ground application. It is a well proven and effective concept for deep space missions. Concatenated convolutional/Reed-Solomon coding, in essence identical to that defined by the Recommendation, will be supported by the DSN and flight proven for deep space use by Voyager 2 at Uranus (Ref. 7). The recommended convolutional coding/decoding has been used by Voyager 1 and 2 from launch and by TDRSS; it will be used by Galileo, ISPM (ESA), Giotto (ESA), and AMPTE (Ref. 8). Galileo and Giotto will use concatenated Reed-Solomon coding very similar to that of the Recommendation (Ref. 9).

Cross support of one agency's spacecraft by another agency's tracking network (Ref. 10) will be simplified by embracing the Recommendation. That will be a benefit to the DSN in the future. Ultimately, when all spacecraft not conforming to the standards have expired, fewer code options will require sustaining and operational support by the DSN. That will reduce DSN support costs.

Although technology developments during the 90's may allow a 1 to 2 dB increase in link capability, the proposed standard is expected to have good longevity through the 90's for deep space mission use. However, it may be that the standard will be modified to permit constraint-length 7 rate 1/3 convolutional codes. This would permit a gain of 0.5 dB (Ref. 6) at little additional complexity on spacecraft and ground. Thus, the Coding Recommendation was endorsed to OSTDS as desirable for the DSN and NASA.

C. Assessment of Packet Telemetry Recommendation

1. **Description.** The Recommendation assessed was CCSDS Blue Book, Draft, Issue-0, February 1984. The packets, consisting of data and an identifying header, are made up by the spacecraft individual data sources. They are asynchronously time multiplexed into the spacecraft data stream. They pass through the system intact to the user of the data. For transfer from the spacecraft through delivery to the Project's mission control, the packets are carried in "telemetry transfer frames." The frames carry information on the mission and instructions for extracting the packets. The frames are multiplexed synchronously into the data stream. On the ground, synchronizing to and reading of the frame header allow the data stream to be directed toward the proper spacecraft Project. Then the individual packets can be demultiplexed and read by the Project (Ref. 11).

The concept enables multimission identification, extraction, and distribution of the data in the stream. It also enables but does not require an adaptive data stream that reacts to events on board the spacecraft. That capability is expected to benefit spacecraft projects and simplify ground processing. The telemetry link efficiency with a data stream compatible with the Packet Recommendation should be comparable to that of current deep space data system designs. Indeed, calculations show that the approximately 0.25 dB average link inefficiency which can be computed (details omitted) for packetized telemetry is about the same as or lower than the inefficiencies computed by the JPL Telecommunications Systems Section (private communication) for Voyager and other fixed-format time-division multiplexed telemetry.

The Recommendation as we have said defines the format for the packets and the transfer frame. The detail in the Recommendation document is sufficient to insure compatibility between users. Several options are available within the Recommendation to handle packets that are longer than a single frame permits. The Recommendation is compatible with, but does not require, per se, the use of the channel coding recommended. It does, however, require low error probability in the channel, as can be provided by proper application of the coding recommendation.

2. Impact on DSN. In concept, the packets, carried by their transfer frames, travel through the ground data system unobserved until they are demultiplexed from their frames at their destination. Therefore, the impact on the DSN is small.

Currently (Ref. 12), the DSN NOCC finds the telemetry frame header and does some demultiplexing to provide data required by DSN performance analysts. The simple algorithm used will not suffice to demultiplex an asynchronous packet stream. However, in the SFOC/NOC era, the DSN NOC is to receive the required information from the SFOC's demultiplexing process. This appears to be a desirable feature of the SFOC/NOC concept, particularly for support of asynchronous packetized data streams.

Full and effective use of the packet data concept requires very low error rates in the end-to-end system. The error probability requirements are two to three orders of magnitude more stringent than generally needed with previous deep space imaging data systems. It is not evident that any system changes to the DSN Complexes or the GCF will be needed solely to support the more stringent requirements.

Surely, however, more rigorous performance validation will be required. The costs have been estimated for providing automatic retransmission or forward error correction on the GCF present or future 56- to 600-kbps wideband data lines. This capability will be appropriate for real-time transmission of high-rate compressed images or packet telemetry. However, the costs ($360K) were not included as a marginal cost for adopting packet telemetry. This is because the capability would only be provided in response to a specific mission requirement and could be driven by missions not using packets, such as missions using data compression (Ref. 3). This low-error capability could also be required by a mission using packets but not in conformance with the CCSDS Recommendations.

The estimated DSN implementation and operational costs to adopt the Packet Telemetry Recommendation are also given in Table 1. The cost impact, without the GCF implementation noted above, is small ($60K). Thus, the Packet Telemetry Recommendation was endorsed to OSTDS as desirable for the DSN and NASA.

D. Considerations for Missions Not Using Telemetry Standards

There are no spacecraft currently designed or in flight that are fully compatible with the Recommendations. For their lifetimes, those spacecraft must be supported by DSN operating modes, or equipment, different from that for standardized spacecraft. Also, it should be anticipated that some future spacecraft designs, for reasons of overall economy, will use "inherited" flight equipment that will result in data systems incompatible with the standards.

For those reasons, for a long time into the future, capability for support of nonstandard spacecraft data systems will have to be retained by the DSN. Even so, adopting the standards is expected to lead to fewer, not more, telemetry designs to support during the period. The basic approach to planning for removal of no longer needed capability in the DSN will be to obtain concurrence of affected projects, both present and potential future, and of affected NASA Centers, before removal of existing capability.

E. Advantages and Disadvantages

Table 2 lists various advantages and disadvantages of the Telemetry Standards that were uncovered in the course of the TDA study. They are listed in the table without quantification. Nevertheless, it is seen that advantages far outweigh disadvantages.

III. TDA Perception of Effect of Standards for Space Data Systems

A. Introduction

This section presents the TDA assessment of how Data System Standards based on the CCSDS Recommendations will affect the way JPL and NASA conduct missions in the future. Issues of cross-support, mission design, mission operations, and space program growth are assessed in this light. The overall conclusion is that the Standards will promote JPL and NASA programs by reducing costs and increasing cooperative ventures.

B. Cross-Support

The greater interoperability that the Standards enable will make it easier for NASA to give and get cross-support. A greater number of cooperative missions between space agencies, such as the International Solar Terrestrial Physics Program (Ref. 13), can be expected. The common performance standard must be maintained high enough so that NASA can receive cross-support as well as give it. This is because NASA's deep space missions usually require performance near attainable limits.

C. Mission Design

The Standards can benefit both the U.S. and International space programs in the mission design phase. It is expected that the Packet Telemetry Standard will facilitate mission-independent instrument integration including re-use and re-flights. Adaptive telemetry and data compression become easier.

D. Mission Operations

The benefits can be substantial, as the SEASAT A operations experience has shown. It will become much easier to handle data from acquisition to distribution and archiving. Common program data, e.g., planetary data system, will be easier to provide. Likewise, coordination of data from multiple spacecraft, such as the ISTP Program and Space Station, will be easier. It will become much easier to have distributed operations and science teams. Common hardware and software are expected to reduce costs in the mission operations system. Overall, the Standards will benefit mission operations.

E. Space Program Growth Potential

The international Space Data System Standards can be a strong factor in the growth of the world's space program. The Standards should cut lead time and cost of experiment integration. Multinational experiments on a space agency's mission will be easier, as well as multispacecraft multiagency missions. Cross-support will be cheaper to obtain or provide, and this in turn can encourage participation by other nations in NASA programs. The availability and utility of space-derived data will increase.

IV. Future Work to Support Standards

For the U.S. to be a full participant in and beneficiary of the international Space Data System Standards program requires a continuing effort. This effort is to evolve the Standards to take advantage of new spacecraft and ground technology and mission concepts. The possibilities for enhancing space programs require a broad planning perspective for NASA, JPL, and TDA within JPL. The TDA responsibility is to determine performance and interface specifications and verify system performance against theory and specification. One change to be encouraged early is to promote the international standardization of the common JPL/GSFC constraint-length 7 rate 1/3 convolutional code as an alternative to the constraint-length 7 rate 1/2 code of the current Guidelines. This can benefit missions which are not bandwidth constrained and can reduce costs or increase science value from the 0.5 dB increase in performance (Ref. 6).

V. Conclusions

The adoption of appropriate standards for space data systems will be of long term benefit to NASA. It will reduce the cost of mission design, implementation, operations, and data analysis. These benefits will be obtained by more thorough development of spacecraft and ground mission and facility designs and operating procedures. Joint ventures between NASA and the space agencies of other nations will be made easier, better, and less costly. Space data will be more available.

Two of the CCSDS Recommendations, Telemetry Coding and Packet Telemetry, have been concurred in by TDA at JPL. They have been well developed and have sound bases. They do not cause noticeable expense to NASA in the near term and can only save in the long term. Concurrence in them was therefore recommended to OSTDS by the TDA Office at JPL.

References

1. Brown, J. W., et al., "Seasat Low-Rate Data System," *Science*, Vol. 204 (1979), pp. 1407-1408.

2. Diaz, A. V., Marcia Neugebauer, J. Stuart, and Richard B. Miller, "New Approaches to Planetary Exploration – Spacecraft and Information Systems Design," *Proc. 1983 International Astronautics Federation General Meeting*, Budapest, Hungary, October 1983, Published by AIAA, 1983, no pp. given.

3. Pierce, John R., and Edward C. Posner, *Introduction to Communication Science and Systems*, Plenum, New York, 1980, Sec. 13.6.

4. Deutsch, L. J., and R. L. Miller, "The Effect of Viterbi Decoder Node Synchronization Losses on the Telemetry Receiving System," *TDA PR 42-68* (April 1982), pp. 17-24.

5. Divsalar, D., and J. H. Yuen, "Performance of Concatenated Reed-Solomon/Viterbi Channel Coding," *TDA PR 42-71* (November 1982), pp. 81-94.

6. Butman, S. A., L. J. Deutsch, and R. L. Miller, "Performance of Concatenated Codes for Deep Space Missions," *TDA PR 42-63* (June 1981), pp. 33-39.

7. Posner, Edward C., and Robertson Stevens, "Deep Space Communication – Past, Present, and Future," invited paper, *IEEE Communications Magazine*, Vol. 22, No. 4 (May 1984).

8. Burt, R., "Mark IV-A DSCC Telemetry System Description," *TDA PR 42-68* (April 1982), pp. 130-138.

9. MacMedan, M. L., "Standard Methods for Telemetry and Telecommand Coding," *Proc. 1983 International Telemetry Conf. (ITC '83)*, San Diego, CA, Oct. 24-27, 1983, published by International Foundation for Telemetring, Woodland Hills, CA, 1983, pp. 839-846.

10. Layland, J. W., et al., "Interagency Array Study Report," *TDA PR 42-74* (Aug. 1983), pp. 117-148.

11. Hooke, Adrian J., "Packet Telemetry and Packet Telecommand: The New Generation of Spacecraft Data Handling Techniques," *Proc. ITC '83* (*op.cit.*), pp. 829-838.

12. Hall, J. R., "Network Control System," *DSN PR Volume XII*, Oct. 1972, pp. 5-11.

13. Wardrop, M. Mitchell, "A New Plan for Space Physics," *Science*, Vol. 222 (22 Oct 1983), pp. 400-401.

Table 1. Estimated DSN marginal costs[a] for implementing Telemetry Channel Coding and Packet Telemetry Recommendations

Standards / Cost Elements	Channel Coding		
	Viterbi Decoding	R-S Decoding[b]	Packet Telemetry[c]
Hardware implementation	47.5	0	0[d]
Software implementation	23.9	0	57.5[d]
Operations	0	0	0

[a]All costs in thousands of FY 84 dollars, ±30% estimate.

[b]Assumes use of current R-S Decoder hardware/software now available in SFOC. If decoding function were shifted to DSN SPC's in future, there would be additional hardware and training costs. However, those costs are independent of adoption of standards.

[c]Assumes fixed length transfer frames as per Recommendation.

[d]Auto recall of GCF WBDL (wideband data lines): cost estimated to \$360K – \$193K for hardware, \$167K for software. Needed only for missions requiring real-time high data rate with low deletions. This would be a mission requirement, if it arises, independent of whether the CCSDS Packet Telemetry Recommendations were adopted.

Table 2. Characteristics and effects of telemetry guidelines

Guideline	Characteristic	Effect
	Positive	
Coding	Common channel coding for all DSN-supported missions	Simplifies all phases (planning through design through operation) of DSN support of all missions (Deep Space, HEO, NASA, Non-NASA)
		Wider base, greater depth of understanding by users of coded channel capability and characteristics
	Cross-support of U.S. missions by other Agencies and conversely	More cross-support potential
	Enables full use of Packet Telemetry	More cross-support potential
	Coding proposed is essentially that evolving as a *de facto* DSN standard for deep space mission support	Builds on considerable DSN investment
		Technology sufficiently mature to support providing a stable standard
		Appropriate time frame for initial establishment of standard
	Allows mission-independent decoder software/hardware	Reduced hardware/software at Complexes
		Reduced effort to test and verify performance for mission set
		Reduced effort for sustaining in Net
	Reed-Solomon/Viterbi provides low error probability for all missions using it without bit power penalty	Low-error-probability engineering telemetry may make isolation of spacecraft vs ground anomalies easier
	Enables mission-independent frame sync	Reduced implementation and test costs and increased confidence
	Negative	
	Retention of old nonconforming designs in overlap period	Increased sustaining engineering costs
	Positive	
Packet	Enhanced ability to obtain cross-support	Reduced NASA costs if facilities of other agencies are needed
	Enhanced ability to provide cross-support	Broader base of DSN customers; more joint missions
	Makes delivery of data to Projects easier	Reduced end-to-end system test and operations costs, increased user satisfaction, and greater cross-support potential
	Eliminates potential need for multiple subcarriers	Fewer Subcarrier Demodular Assemblies and Symbol Synchronizer Assemblies needed at Signal Processing Centers

Table 2. (cont'd)

Guideline	Characteristic	Effect
	Negative	
Packet	Required packet system performance not specified	Potential user surprise and dissatisfaction
	Performance of full adaptive options not specified or understood	Potential need to implement still better coding or provide more signal-to-noise some other way
	Possible complication of project end-to-end testing involving DSN	May increase Signal Processing Center time needed for testing
	Need to retain non-packetized telemetry for old designs	Possible enlarged complexity in Telemetry Processing Assembly and increased sustaining

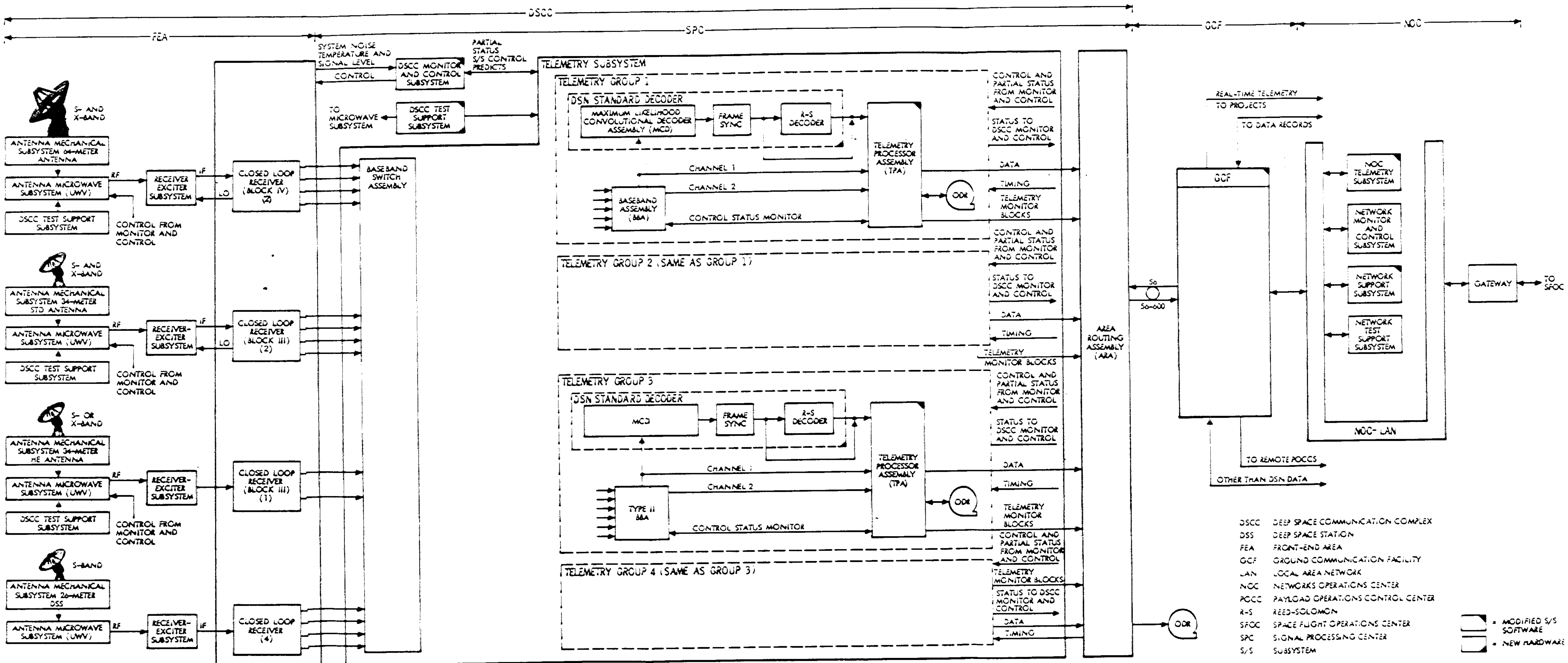

Fig. 1. Baseline 1986–90 era DSN Telemetry System